Mangalore University

Synopsis of the **PhD thesis**

on

Impact of Anthropogenic Activities on the Chemistry of Atmospheric Components along the South-West coast of India

for the award of the

Doctor of Philosophy

in

Marine Geology (under the Faculty of Science)

by

Rajesha R
Part-time Research Scholar,
Department of Marine Geology
Mangalore University
Mangalagangothri-574199

under the guidance

Dr. B.R. Manjunatha
Professor
Department of Marine Geology
Mangalore University
Mangalagangothri-574199

June 2022

Mangalore University

Department of Marine Geology

Mangalagangothri-574199

Title of the thesis	**Impact of Anthropogenic Activities on the Chemistry of Atmospheric Components along the South-West coast of India**
Name of Candidate	**Rajesha R**
Name of Gide and Designation:	**B.R. Manjuantha** Professor Department of Marine Geology Mangalore University Mangalagangothri-574199
Department:	**Marine Geology**
Date of Registration:	28th December 2013
Registration number:	MU/EXB/PhD/CR.123/MG/2014-15/E.13
Extension (due to the pandemic **Covid-19**) reference	MU/EXB/PhD/CR.123/MG/2014-15/E.13 (Date: 10.11.2021) MU/EXB/PhD/CR.123/MG/2014-15/E.13 (Date:01.02.2022)
Place of work	Department of Marine Geology Mangalore University Mangalagangothri-574199

Contents

Sl. No.	Content's title	Page no.
1	Introduction	1
2	Area of investigation	6
3	Objectives	8
4	Thesis format	8
5	Selected references	13

Introduction

The most important life-supporting system on earth is the atmosphere in terms of providing not only gaseous oxygen for respiration but also wind and rainfall, although the latter is connected to the land and the ocean. The composition of various gaseous matter present in the air is largely responsible for the structure of the atmosphere. The atmosphere of the Earth is made up of 78 % nitrogen, 21% oxygen, and 0.93 % argon. Water vapour, carbon dioxide, and ozone are among trace gases found in the remaining 0.1 %. All of these trace gases have a significant impact not only on the global climate but also affect monsoon rainfall (Singh, 2000; Berner and Berner, 1996, 2012; Mackenzie, 1998, 2011; Sharma et al., 2017; Singh et al., 2017; Sarangi et al., 2018; Zan et al., 2019; Krishnan et al., 2020; Hamilton et al., 2022; Li et al., 2022). In addition to atmospheric gases, atmospheric particles play a significant influence in the physical and chemical processes that occur in the atmosphere. Atmospheric particles have a significant influence on the formation of cloud droplets of water and ice crystals (Choularton et al., 2008). Furthermore, without the active participation of atmospheric particles, their nutritive/hazardous property and their involvement in the biogeochemical cycles are incomplete. Fine-sized particles in the atmosphere play a significant role in the occurrence of acute and chronic human health disorders, according to research conducted in different parts of the world (Robert and Gokhan, 2018). Black carbon aerosols contribute significantly to positive radiative forcing among fine particles in the

atmosphere that affects health as well as aircraft and land vehicles (IPCC, 2013). With increasing urbanisation and ineffective infrastructural management and planning, air pollution has become a strong problem in developing countries like India.

Environmental pollution is the result of unfavourable changes in our environment that harm plants, animals, and humans. Since the beginning of the industrial revolution in the 17 century, human beings have added a substantial amount of greenhouse gases into the atmosphere by combustion of fossil fuels, deforestation, biomass burning and changes in the land-use pattern. Consumption of fossil fuels liberates greenhouse and acid-generating gases like CO_2, CH_4, NO_x, and SO_2, and associated toxic metals into the Earth's surficial environments. Sometimes, natural processes such as forest fires, desert dust storms, and volcanoes have significant impacts on the global climate (Rodhe and Herrera, 1988, Rodhe et al., 1995; Naqvi et al., 2000; Ramanathan et al., 2001; Berner and Berner, 1996, 2012; Mackenzie, 1998, 2011).

Research in an atmospheric deposition has increased a great deal over the past years because of its increasingly significant contribution to the explanation of pollution phenomena in many compartments, along with the possibility to evaluate the impacts of pollution sources from long and short distances (as in fugitive emissions) and the possibility to carry out long-term studies aimed at performing health impact assessments on exposed populations (Amodio et al., 2014). Atmospheric deposition can occur through wet or dry

pathways. Wet deposition is the process by which gases and aerosols are deposited on the earth's surface, mainly in the form of rain, snow, or mist (Seinfeld, turbulent and Brownian transfer and by gravitational settling from the atmosphere to the earth's surfaces (Lovett, 1994, and Mészaros et al. 1999; Solomons and Forstner, 1984; Yang et al., 2019). A large amount of smoke generated by 10 to 12 billion tons of combustion of fossil fuel every year has not only altered the atmosphere but also ocean acidification (Panchang and Ambokar, 2021; Nriagu and Pacyna, 1988; Nriagu, 1989; Duce et al., 1991; 2008; Spokes et al., 1994; Andreae and Crutzen, 1997; Pacyna and Pacyna, 2001; Ramanathan et al., 2001; Prospero et al., 2003; Goel and Kumar 2014). Particulate matter (PM) is one of the most common pollutants in the ambient air, and despite strict pollution control programmes, cities all over the world frequently exceed regional and/or national air quality regulations (Pallavi Pant et al. 2016). The particle size of the above-mentioned types has been measured, which is an important indication of the sources of particles in the atmospheric compartment. The amount and characteristics of atmospheric deposition will depend on the local atmospheric pollutant load, the meteorology, and the transport patterns from emission sources to receptor sites (Sonia et al., 2017). The accumulation of atmospheric particles may alter the earth's radioactive balance, modifying the physical and chemical properties of clouds and so affecting rainfall, climate change, and human health (Bahadur et al., 2012; Berner and Berner, 1998, 2012; Feng et al., 2013; Warrier et al., 2015)

1.1. Background information

On all continents, the urban population as well as expansion, in particular, the coastal zone is growing to a greater extent (Mackenzie, 1998; Florczyk et al., 2019; Dijkstra et al., 2009). The fastest urban population growth occurs in developing and emerging countries. The Northern Indian Ocean (NIO) is one of the world's unique oceans in terms of seasonal/semi-annual atmospheric circulation as well as a strong impact from anthropogenic activities occurring in the surrounding continental regions. This ocean is divided into two branches in the northeastern part the Bay of Bengal and the Arabian Sea in the north-western which is influenced by the desert. While the Bay of Bengal is dominated by fluvial input. The seasonal/semi-annual reversal of atmospheric and ocean circulation happens as a result of variations in land and ocean heating during the summer and winter seasons (McCreary et al., 2009). This is the main reason for the difference in the monsoon circulations during summer and winter.

1.2. Review of Literature including international and national

The literature review for the thesis was conducted by using information gathered from the internet, visiting different libraries as well as material provided by the research supervisor. Air pollution is one of the world's most serious issues today.

The earth systems have a close association with the atmosphere, land and oceans. Although oceans account for about 71% of the earth's surface, the continents are more important, especially human beings in driving the weather and climate on earth (Mackenzie, 2011; Berber and Berner, 2012; Singh et al., 2017; Saringi et al., 2018; Häder et al., 2022; Hamilton et al., 2022). The atmospheric components can be grouped into the most dominant gaseous phase, followed by aerosols which are either solid particles or liquid droplets.

The soil resuspended dust is the solid particles, mainly in the large size fractions as compared to aerosols.
Atmospheric components, generally dust, aerosols and anthropogenic ones are a short residence time. The best instance to prove this is the considerable reduction in the atmospheric pollution noticed during the Covid-19 lockdown periods (Wang et al., 2022).

The size of atmospheric particles varies from as low as nanoparticle size to a few 100s of micron diameter, which can be grouped as nucleation mode (0.05 μm to 0.63 μm), accumulative mode 0.63 μm to 1.26 μm and coarse particles (2.5 μm to >10μm to 500 μm; Willeke and Whitby, 1975; Whitby, 1977; Solomons and Forstner, 1984; Berner and Berner, 2012; Gonet and Maher, 2019). In the industrial and urban regions, the atmospheric particle size ranges vary considerably from nucleation mode to accumulative mode, whereas in desert regions the particles are in the coarse mode. Therefore, the particle size itself provides information about the processes operating in the earth system (Hosker and Lindberg, 1982; Hofman et al., 2017; Lasko et al., 2018;

Kumar et al. 2019; Yang et al., 2019; Zan et al., 2019; Souza et al., 2021).

The work related to atmospheric components and rainwater chemistry was not much before three decades, however, this aspect gained maximum importance since then Duce et al., 1991; Chester, 1990; Jickellls et al., 2005; Chester and Jickells, 2012; Jickells and Moore, 2015; Guieu et al., 2019). This is mainly due to the importance of the atmosphere that any perturbance on it will have implications for the global climate change and alteration of the monsoon rainfall (Krishnan et al., 2020 and references cited therein).

2. The Area of Investigation

The west coast of India and the adjoining Western Ghats Plateau Mountains are receiving heavy monsoon rainfall (200-500 cm/yr). The southern part of the former one, - the southwest coast of India is the populated and industrialised region.

Environmental problems of this are deforestation, land erosion in the upper part of the Western Ghats, increased siltation in the lower course of rivers and coastal regions as well as the build of contaminants in the atmosphere horizon and to some certain extent in river valleys and coastal environments are generally known environmental problems. There is not much research related to the atmosphere and its impact on the terrestrial environment. Therefore in this study, the major and trace elements of rainwater and water-soluble dust atmospheric particles have been studied to know the impact of anthropogenic and anthropocentric activities.

The important industries established in the study area, particularly at the Kochi monitoring station are petroleum refineries, zinc smelters, chemicals and fertilizers plants, copper sulphate, coir and alkali plants, tile and brick industry, cement manufacturing plants, rare earth elements extraction plants, etc.

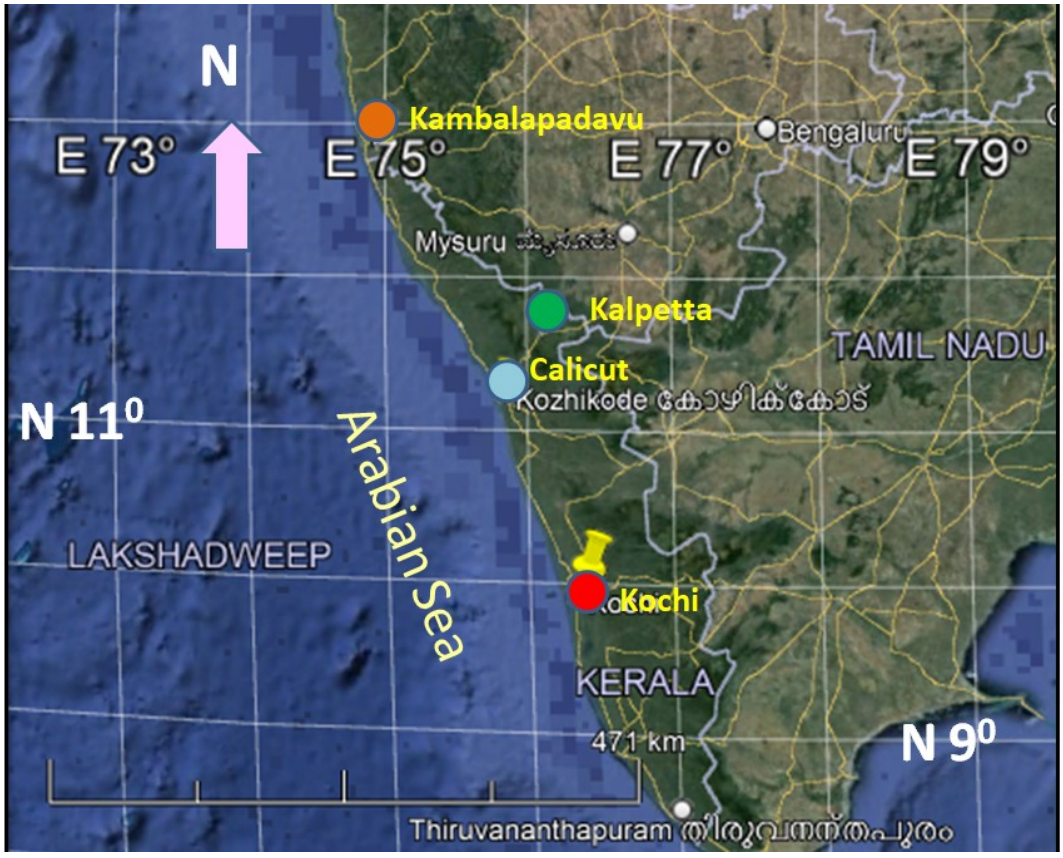

Figure 1. Map of the study area showing sample monitoring station along the southwest coast of India.

The study area is the southwest coast of India and the adjacent Western Ghats. Three sampling monitoring stations have been selected for this work to understand the natural and human impacts of the atmospheric components (Fig. 1). Station -1 is the northernmost part of the study are (1)

KambalaPadav, near Mangaluru, (2) background monitoring, for this study, at Kalpetta, Wayanad District, (3) urbanized region Calicut/Kozhikode and (4) proximity of industrialized area of Kochi. The station-2 is on the peak of Western Ghats and the latter three are along the southwest coast of India.

3.Objectives

Based on the scope of the area of investigation, the main objectives of the study are to:

- To determine the sources, and fortnightly variations of major ions and trace elements in rainwater and atmospheric particulate matter (dust), to understand natural processes and anthropogenic impacts.

- Distinguish between local and regional pollution based on the chemistry of rainwater and aerosols, and

- Evaluate the relative magnitudes of elemental fluxes from natural and anthropogenic sources to the coastal environment and their biogeochemical implications.

4. Thesis format

The thesis is divided into seven sections. In addition, the criteria for classifying chapters were based on compositional fluctuation with seasons, types of samples, and chemical analysis procedures used.

Chapter 1: Introduction

This chapter gives an overview of the present understanding of atmospheric chemical processes as well as their impacts and inputs on terrestrial and marine environments. Here, overviews of the global review along with regional and local research carried out are discussed to identify the work to be done in the area of study with the following objectives of the thesis: In addition, information about the intention of anthropogenic assessment of atmospheric pollution is discussed based on the comparison of results from the relatively pristine region with urban and industrial anthropocentric regions of the study area and its implications for marine productivity.

Chapter 2: Materials and Methods

This chapter provides details of the protocol followed during the collection of samples, criteria for selecting the sampling stations, sampling procedure, pre-treatment, and details of methods. By using bulk precipitation collectors, atmospheric samples were collected at the three stations mentioned earlier, at fortnightly to monthly intervals from 2013 to 2015. This has been done by using a large size (15-inch) poly-propylene funnel (with bird guard and tygone tubing to avoid bird dropping contamination to samples and to minimize evaporation water from the sampler). Samples of the bulk precipitation collected were filtered by using Millipore cellulose acetate membrane filters (0.45 m pore size). After filtration, a part of the samples was used for

measuring Physico-chemical parameters such as pH and electrical conductivity. The remaining samples were split into two parts; in one half, thymol preservative was added for the measurement of major ions by ion chromatography; in the other half, samples were acidified with ultra-pure nitric acid for trace elemental analysis by ICP MS. The data so obtained was statistically analysed to simplify the results and draw meaningful conclusions.

The laser-diffraction particle size analysis was performed for rain and dust samples using Sequoia LISST-PORTABLEXR. The composition and concentration of particles in the atmosphere are two factors that influence the radiative heat balance on Earth. atmospheric particles depends also on their size, density, and wind velocity. Generally, the fine particles in the atmosphere originate from the dry soil that easily erodes during the dry season and has an adverse effect not only on the climate but also on human health. Similarly, the climate is affected by major gases like nitrogen, carbon, and oxygen.

The large amount of data generated in this study is discussed in the following chapters, with the summary and conclusions at the end of the thesis.

Chapter 3: Meteorology and the deposition of atmospheric particulate matter in the study area

This chapter gives an overview of the techniques used to quantify atmospheric particle deposition, including those scavenged by rain and dust fallout from dry depositional processes. In these studies, quantification of air particle deposition scavenged by rain and dust falling from dry

depositional processes was used. For nearly two years, samples were collected at fortnightly to monthly intervals. Seasonal and annual atmospheric dust depositions have been examined concerning the expected source regions surrounding India's southwest coast. The results are compared and validated using dry dust deposition and rainfall, as well as satellite data.

Chapter 4: Size of atmospheric particulate matter and air-mass trajectories of the study area

Since four atmospheric monitoring sites were chosen for this study, a large number of samples were collected and analysed for particle size distribution to better understand the mode of origin and seasonal fluctuations as well as their impact on the natural ecosystem. The back trajectories are calculated with the help of the NOAA HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory). Back trajectory analysis makes it feasible to identify geographic source sites for certain atmospheric components.

Chapter 5: Composition of rainwater and water-soluble proportion of the atmospheric particulate matter

This chapter provides details on the local and regional atmospheric inputs to the southwest coast of India. The water-soluble fraction of atmospheric particles is evaluated to distinguish between natural and human-made fluxes. The emphasis of this study is on the spatial and temporal variability of various water-soluble major ions, nutrients, and pollutants found in atmospheric particles. For some

representative dust and rainwater samples, the data used in this chapter are water-soluble proportions of main ions, trace elements, and nutrients.

Chapter 6: Anthropogenic and Anthropocentric Developments and their impact on the Atmosphere over the study area

This chapter explains how seasonal and yearly changes in the industrial region compared to the urban areas have been used to discuss the influence of urbanisation the anthropogenic air quality. This study evaluates the interannual fluctuations in the atmospheric concentrations of Sulfur Dioxide (SO_2), Nitrogen Oxide (NO_2), and respirable suspended matter (RSPM). The data (from 2007 to 2019) was utilised for identifying anthropogenic effects and the effects of human activities have an impact on the atmosphere.

Chapter 7: Summary and conclusions

This chapter contains an overview of the data, the results, and the discussion followed by conclusions. The importance of atmospheric inputs in the form of atmospheric particles has been studied in the high rainfall region of India's tropical southwest coast. The implications for human impacts on climate and primary productivity in the South-Eastern Arabian Sea are discussed. This is followed by the summary and conclusions.

Selected References

Amodio M, S. Catino, P. R. Dambruoso, G. de Gennaro, A. Di Gilio, P. Giungato, E. Laiola, A. Marzocca, A. Mazzone, A. Sardaro, andM. Tutino.,(2014) Atmospheric Deposition: Sampling Procedures, Analytical Methods, and Main Recent Findings from the Scientific Literature. Hindawi Publishing Corporation Advances in Meteorology, Volume 2014, Article ID 161730, 27 pages

Andreae, M., Crutzen, P. J., 1997. Atmospheric aerosols: Biogeochemical sources and

Bahadur, R., Praveen, P. S., Xu, Y., and Ramanathan, V. (2012) Solar absorption by elemental and brown carbon determined from spectral observations, P. Natl. Acad. Sci. USA, 109, 17366–17371, doi:10.1073/pnas.1205910109.

Berner, E. K., & Berner, R. A. (2012). Global environment: water, air, and geochemical cycles. Princeton University Press

Berner, E.K., Berner, R.A., 1996 The Global Water Cycle: Geochemistry and Environment. Prentice-Hall Inc., N.J., 397p.

Chester R & T. Jickells 2012. Marine Geochemistry, 3rd ed. viii 411 pp. Wiley-Blackwell, Geological Magazine, 150(4), 765-765.

Chester, R., 1990. “Marine Geochemistry”, Unwin Hyman, London, 698p.

Choularton, T. W., Bower, K. N., Weingartner, E., Crawford, I., Coe, H., Gallagher, M. W., Flynn, M., Crosier, J., Connolly, P., Targino, A., Alfarra, M. R., Baltensperger, U., Sjogren, S., Verheggen, B., Cozic, J., and Gysel, M.: The influence of small aerosol particles on the properties of water and ice clouds, Faraday Discuss., 137, 205–222, 2008.

Dijkstra L P 2014 A harmonised definition of cities and rural areas: the new degree of urbanization Directorate-General for Regional and Urban Policy Working Papers

Duce, R. A., Liss, P. S., Merrill, J. T., Atlas, E. L., Buat-Menard, P., Hicks, B. B., et al. (1991). The atmospheric input of trace species to the world ocean. Global Biogeochemical Cycles, 5(3), 193–259. https://doi.org/10.1029/91GB01778.

Feng, Y., Ramanathan, V., &Kotamarthi, V. R. (2013). Brown carbon: a significant atmospheric absorber of solar radiation? Atmospheric Chemistry and Physics, 13(17), 8607–8621. doi:10.5194/ACP-13-8607-2013.

Florczyk A J et al 2019 GHS Urban Centre Database 2015, multitemporal and multidimensional attributes, R2019A European Commission, Joint Research Centre (JRC) Geophysical Research Letters, 46, 6736−6744.

Gonet, T., and Maher, B.A., (2019). Airborne, vehicle-derived Fe-bearing nanoparticles in the urban environment − A review. Environmental Science &Technology. doi:10.1021/acs. est.9b01505, 2019

Guieu, C., Al Azhar, M., Aumont, O., Mahowald, N., Levy, M., Ethé, C., &Lachkar, Z. (2019). The major impact of dust deposition on the productivity of the Arabian Sea.

Häder, D.; Banaszak, A.T.; Villafañe, V.E.; Narvarte, M.A.; González, R.A.; Helbling, E.W. Anthropogenic pollution of aquatic ecosystems: Emerging problems with global implications. Sci. Total Environ. 2020, 713, 136586.

Hamilton, D.S.; Perron, M.M.G.; Bond, T.C.; Bowie, A.R.; Buchholz, R.R.; Guieu, C.; Ito, A.; Maenhaut, W.; Myriokefalitakis, S.; Olgun, N.; et al. Earth, wind, fire, and pollution: Aerosol nutrient sources and impacts on ocean biogeochemistry. Annu. Rev. Mar. Sci. 2022, 14, 303–330

Hofman, J., Maher, B.A., Muxworthy, A.R., Wuyts, K., Castanheiro, A., Samson, R., (2017). Biomagnetic monitoring of atmospheric pollution: A review of magnetic signatures from biological sensors. Environ. Sci. Technol., 51, 6648−6664.

Hosker, R.P. and Lindberg, S.E. (1982) Review Article: Atmospheric Deposition and Plant Assimilation of Airborne Gases and Particles. Atmospheric Environment, 16, 889-910. http://dx.doi.org/10.1016/0004-6981(82)90175-5

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex

and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M., Kulkarni, A., Chakraborty,

Kumar, S., Prasad, S., Yadav, K. K., Shrivastava, M., Gupta, N., Nagar, S., Malav, L. C. (2019). Hazardous heavy metals contamination of vegetables and food chain: Role of sustainable remediation approaches- A review. Environmental Research, 108792.

Lasko K, Vadrevu K, Tran V, Justice C. Mapping of double and single crop paddy rice using Sentinel-1A imagery at varying spatial scales and polarizations in Hanoi, Vietnam. IEEE Journal of Selected Topics in Applied Earth Observation and Remote Sensing. 2018;11(2)

Li, P.; Chen, X.; Niu, H.; Lu, Z.; Zhang, Z.; Lin, G.; Yuan, K. An Advanced PMF Model Based on Degradation Process for Pollutant Apportionment in Coastal Areas. Water 2022, 14, 1823.

Lovett, G.M. Atmospheric deposition of nutrients and pollutants in North America: An ecological perspective. Ecol. Appl. 1994, 4, 629–650.

Mackenzie, F. T., 1998. Our Changing Planet: An Introduction to Earth System Science and Global Environmental Change. II Edition, Printice Hall, N.J. 486p.

Mackenzie, F. T., 2011. Our Changing Planet: An Introduction to Earth System Science and Global Environmental Change. IV Edition, Printice Hall, N.J. 579p

McCreary, J., R. Murtugudde, J. Vialard, P. Vinayachandran, J. D. Wiggert, R. R. Hood, D. Shankar, and S. Shetye (2009), Biophysical processes in the Indian Ocean, in Indian Ocean Biogeochemical Processes and Ecological Variability, AGU, Washington, D.C. pp. 9–32

Mészaros, E. Fundamentals of Atmospheric Aerosol Chemistry; Akadémiai Kiado: Budapest, Hungary, 1999.

Naqvi, S. W. A., Jayakumar, D. A., Narvekar, P. V., Naik, H., Sarma, V. V. S. S., D'Souza, W., Joseph, S., and George, M. D.: Increased marine production of N2O due to intensifying anoxia on the Indian continental shelf, Nature, 408, 346–349, 2000.

Nriagu, J. O., Pacyna, J. M., 1988. Quantitative assessment of worldwide contamination of air, waters and soils by trace metals. Nature 333, 134-139.

Nriagu, J.O., 1989. Natural versus anthropogenic emissions of trace metals to the atmosphere. In: PACYNA, J.M. and OTTAR, B. (eds.), 1989. Control and Fate of Atmospheric Trace Metals. Kluwer Academic Publishers, NATO ASI Series vol.268, pp. 3-13.

Pacyna, J. M., Pacyna, E. G., 2001. An assessment of global and regional emissions of

Pallavi Pant a, Stephen J. Baker a, Rahul Goel b, Sarath Guttikunda b, c, Anubha Goel d, Anuradha Shukla e, Roy M. Harrison (2016) Analysis of size-segregated winter season aerosol data from New Delhi, India. Atmospheric Pollution Research 7 (2016) 100-109

Panchang, R. and Ambokar, M., 2021. Ocean acidification in the Northern Indian ocean : A review. Journal of Asian Earth Sciences, 219 2021, 104904

Ramanathan V., Crutzen, P. J. Kiehl, D Rosenfeld. (2001) Aerosols, Climate, and the Hydrological Cycle. www.sciencemag.org SCIENCE VOL 294, 2119-2124.

Robert B Hamanaka, Gokhan Mutlu M. Particulate Matter Air Pollution: Effects on the Cardiovascular System. Front Endocrinol (Lausanne). 2018 Nov 16;9:680. doi: 10.3389/fendo.2018.00680. PMID: 30505291; PMCID: PMC6250783.

Rodhe, H., Herrera, R. 1988. Acidification in Tropical Countries, John Wiley, New role in atmospheric chemistry. Science 276, 1052-1058.

Rodhe, H., Langner, J., Gallardo, L., Kjellstrom, E., 1995. Global scale transport of acidifying pollutants. Water, Air and Soil Pollution 85, 37-50.

S., 2020. Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India. pp. 226. https://doi.org/10.1007/ 978-981-15-4327-2.

Sarangi, C., Kanawade, V. P., Tripathi, S. N., Thomas, A. &Ganguly, D. Aerosolinduced intensification of cooling effect of clouds during Indian summer monsoon. Nat. Commun. 9, 3754 (2018).

Sharma, D., and R. L. Miller (2017),Revisiting the observed correlation between weekly averaged Indian mon-soon precipitation and Arabian Sea aerosol optical depth,Geophys. Res.Lett.,44, 10,006–10,016, doi:10.1002/2017GL074373.

Singh, C., Ganguly, D. & Dash, S. K. Dust load and rainfall characteristics and their relationship over the South Asian monsoon region under various warming scenarios. J. Geophys. Res. 122, 7896–7921 (2017).

Singh, S (2000). Trace Gas Emissions and Plants. 10.1007/978-94-017-3571-1.

Solomons, W. and Förstner, U. (1984) Metals in the Hydrocycle. Springer Verlag, Berlin, 349 p. https://doi.org/10.1007/978-3-642-69325-0

Sonia Castillo, Andrés Alastuey, Emilio Cuevas, Xavier Querol and Anna Avila (2017) Quantifying Dry and Wet Deposition Fluxes in Two Regions of Contrasting African Influence: The NE Iberian Peninsula and the Canary Islands Atmosphere 2017, 8, 86; doi:10.3390/atmos8050086

Souza, I. d. C.; Morozesk, M.; Mansano, A. S.; Mendes, V. A.; Azevedo, V. C.; Matsumoto, S. T.; Elliott, M.; Monferrán, M. V.; Wunderlin, D. A.; Fernandes, M. N. Atmospheric particulate matter from an industrial area as a source of metal nanoparticle contamination in aquatic ecosystems. Sci. Total Environ. 2021, 753, 141976, DOI: 10.1016/j.scitotenv.2020.141976

Spokes, L. J., Jickells, T. D., and Lim, B. (1994) Solubilisation of aerosol trace metals by cloud processing: A laboratory study, Geochimica et Cosmochimica Acta, 58, 3281–3287, 10.1016/0016-7037(94)90056-6.

trace metals to the atmosphere from anthropogenic sources worldwide. Environmental Reviews 9, 269-298.

Wang, Y., Wu, R., Liu, L., Yuan, Y., Liu, C., Ho, S. S. H., Wang, Q., Lv, Y., Yan, M., & Cao, J. (2022). Differential health and economic impacts from the COVID-19 lockdown between the developed and developing countries: Perspective on air pollution. Environmental Pollution, 293, 118544.

Warrier, A.K., R. Shankar, B.R.,/ Manjunatha, B.G.., Harshavardhana., 2014 Mineral magnetism of atmospheric dust over the southwest coast of India: Impact of anthropogenic activities and implications to public health. Journal of Applied Geophysics 102 pp 1–9.

Whitby, K.T., 1977. The physical characteristics of sulfur aerosols. Atmospheric Environment 12, 135-159.

Willeke, K., Whitby, K.T., (1975) Atmospheric Aerosols: Size Distribution Interpretation; J. Air Pollut. Control Assoc., 25 (5), 529-534.

Yang, L., Mukherjee, S., Pandithurai, G. et al. Influence of dust and sea-salt sandwich effect on precipitation chemistry over the Western Ghats during summer monsoon. Sci Rep 9, 19171 (2019). https://doi.org/10.1038/s41598-019-55245-0 York, 405p.

Zan, J., Fang, X., Li, X., Yan, M., Kang, J. 2019. Long-term variations in the lithogenic susceptibility of Chinese eolian deposits since the late Pliocene. Geophys. Res. Lett. 46, 726–735.

Signature of the Student Signature of the Supervisor

Date…… Date……